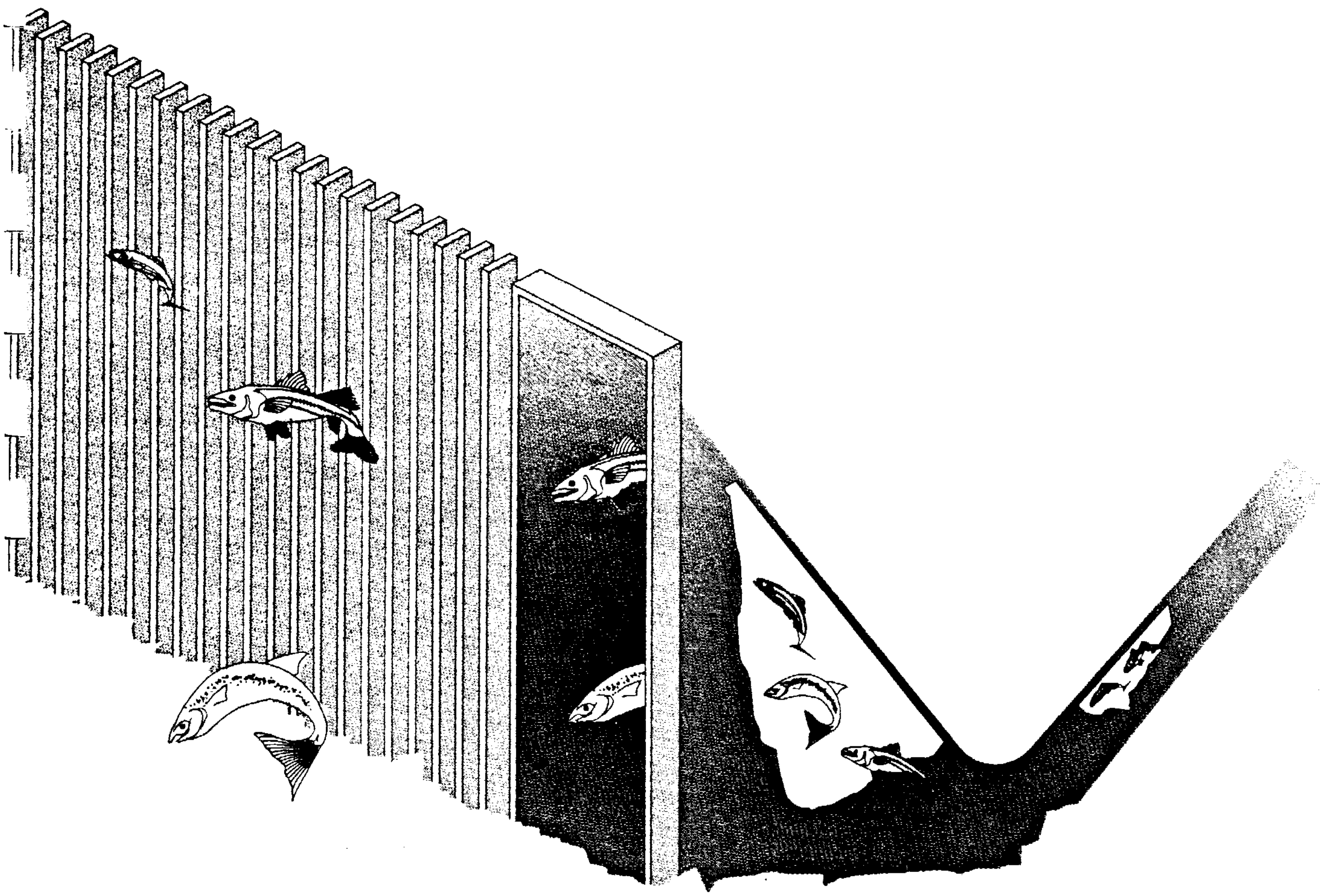

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Volume 3

Re-Evaluation of Louver Efficiencies for Juvenile Chinook Salmon and Striped Bass at the Tracy Fish Collection Facility, Tracy, California, 1993

United States Department of the Interior
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TABLE OF CONTENTS

TABLES

Table of Contents--Continued

Tables--Continued

FIGURES

Tracy Fish Collection Facility Studies, California
Volume 3: Re-evaluation of Louver Efficiencies for Juvenile Chinook Salmon and Striped Bass at the Tracy Fish Collection Facility, Tracy, California, 1993

PREFACE

The following report is the third volume in the Tracy Fish Collection Facility Studies series. These studies are investigating a variety of issues that are concerned with improving overall fish salvage at the Tracy fish facility. The first volume summarized the 1991-92 predator removal program and intake channel studies (Liston et al. 1994). The second volume summarized the 1991-92 fish egg and larvae continuous sampling program (Hiebert 1995). This volume summarizes the louver efficiency experiments conducted at the fish facility in 1993 (see Appendix for conversion from the metric system to the English system).

ABSTRACT

The Bureau of Reclamation's Tracy Fish Collection Facility was constructed in the mid-1950's as part of the Central Valley Project. The facility uses a louver-bypass type of fish diversion system to separate fish from the exported flow. The fish are collected and held in holding tanks where they await transport back to the Sacramento-San Joaquin Delta. The louver system design was based on field tests conducted with young striped bass and chinook salmon (Bates et al. 1960; Hallock et al. 1968) and is generally believed effective for fish large enough (>38 mm) to detect them. However, its current efficiency is not well known not only for these species but also for the other 35+ fish species that are entrained in the export flows. We began to re-evaluate louver efficiencies for juvenile chinook salmon and striped bass using mark-release-recapture techniques. We defined louver efficiency as the proportion of fish recovered in the holding tanks relative to the number released upstream of each louver system. A total of 12 groups of juvenile striped bass and chinook salmon were released at four to six sites within the facility at various flow, tide, and day/night conditions. Holding tank recoveries were monitored for at least two hours following release. The majority of the fish that were louvered were recovered in the holding tanks within the one to two hour period following release. The secondary louvers were generally more effective ($\bar{x}$ = 80.0%, range: 72 - 100% for chinook salmon and 30 - 90% for striped bass) than the primary louvers ($\bar{x}$ = 59.3%, range: 13 - 82% for chinook salmon and 0 - 96% for striped bass) at diverting fish from the flow. However, fish released into the primary channel had greater opportunity to move upstream and away from the facility, or downstream either through the louvers or through the gap created by the primary louver cleaning process. These fish also may have been more vulnerable to predation, or may have found refuge within the system. Louver efficiencies of fish released at the trash-boom were generally similar to that of fish released directly into the primary channel. Louver efficiency appeared to decline as the louvers became clogged with debris (e.g., first two November experiments) and during the process of lifting the primary louvers for cleaning. Our experimental efficiencies were slightly lower than previously reported estimates, and we recommend a more comprehensive evaluation of flow dynamics (velocity profiles) and louver efficiency be conducted at the Tracy Fish Collection Facility to further identify conditions that enhance louver efficiency.

INTRODUCTION AND BACKGROUND

The Central Valley of California includes the Sacramento River drainage from the north, the San Joaquin drainage from the south, and outflows from several east-side tributaries. These systems converge in the central portion of the state forming a huge natural estuary (western portion known as the Delta) whose hydraulics are influenced by many factors including tides, precipitation, freshwater outflows, export pumping, irrigation practices, etc. (Figure 1). The Central Valley Project (CVP) was authorized by Congress in 1934 to regulate flows in the Central Valley to provide water for irrigation. The CVP has been operated by the U.S. Bureau of Reclamation since its inception.

The Tracy Pumping Plant (TPP), Tracy Fish Collection Facility (TFCF), and Delta Mendota Canal (DMC) facilities in the Delta Division of the CVP, operate to export water for irrigation, municipal, and industrial needs in the south central valley while reducing associated fish losses. The TPP is one of two large pumping plants in the south Delta (the other is the state operated Harvey O. Banks Delta Pumping Plant). The TPP draws water off the Old River channel of the lower San Joaquin River into the inlet to the DMC (known as the intake channel) where it passes through the TFCF (Figure 2). The TFCF is a large fish diversion and salvage facility that operates to divert fish from the flow before it is lifted into the DMC by the TPP. These facilities are located in the south Delta about 14.4 km northwest of Tracy, California.

The Tracy CVP facilities were constructed in the mid-1950's to export water. The TPP, intake channel, and a pilot fish screening structure (site of the present TFCF) were completed in 1951. In 1952, Reclamation, in cooperation with the U.S. Fish and Wildlife Service, and California Department of Fish and Game, began testing various types of fish screening devices at the pilot structure to reduce impacts of pumping on striped bass, chinook salmon, catfish, and shad (USDOI 1957). After two years of testing, Reclamation determined that a system of louvers, bypasses, and collection/holding tanks was most effective at diverting fish from the debris-laden flow of the South Delta. The final design was completed in 1955 and by 1957, the current fish facility was in operation. The original louvers were replaced in the early 1990's following the same design.

The fish diversion system at the TFCF uses a louver-bypass-collection system to divert fish from exported flow (Figure 2). The louver sections are a framework of evenly spaced (23.4 mm openings) vertical slats that traverse the channel and allow water to pass to the pumps while creating some turbulence which the fish can detect. Design of the louver system at the TFCF was based on observations that fish orient into the flow, but when faced with an obstruction, move laterally to be swept downstream (Bates and Visonhaler 1956). Thus, the fish guide along the louver face and eventually are carried into a bypass opening. The probability that a fish will be louvered (or guided into a bypass opening) is most strongly influenced by its' swimming ability and size, and the approach velocity (EPRI 1986). Other factors include the amount of debris clogging the louver spaces, bypass velocities, predator load, day/night, etc.

There are three louver arrays at the TFCF. The first or primary louver system is about 97.5 m long and is angled 15° to an 25.6 m wide channel. There are four 15.2-cm bypass openings (one occurring about every 22.9 m) which lead into 91.4 cm diameter pipes that lead to the secondary louver system. The second louver system includes two parallel lines of louvers (25.6 m long) that span the 2.4 m wide secondary channel also at a 15° angle. Fish and entrained material diverted by this system enter a common bypass opening which feeds into four large circular holding tanks (flows are directed into one tank only at any one time). The second louver system was added to concentrate the collected fish and reduce the volume of water entering the holding tanks. Fish (and debris) are regularly removed from the holding tanks and returned to the Delta.

The louver structures are protected by a surface trash-boom which concentrates and directs floating debris to a conveyor belt for disposal, and by a trash-rack with bars spaced at 53.9 mm intervals (Figure 2). These function to keep large debris from entering and damaging the primary louver system. The trash-rack also prevents large fish from entering the facility which limits predation on smaller fish moving through the system. The trash-rack and louvers become heavily clogged with river debris (primarily aquatic plants) at various times throughout the year. Consequently, these structures are cleaned daily or more often as needed as debris accumulation reduces their effectiveness at deflecting fish from the flow.

The louver system at the TFCF was designed to divert and collect young (> 25 mm) striped bass and downstream migrating chinook salmon smolts from the exported flow (Bates and Visonhaler 1956). During the first few years of operation, pumping was mostly restricted to the summer months, a time when young salmon were less vulnerable to entrainment by the pumps. This period of peak pumping did coincide with the presence of large numbers of larval and post-larval striped bass, however, it was believed that the louver-bypass system diverted most of these fish.

The current practice of year-round pumping at high rates (and consequently higher velocities) was instituted in the late 1960's with construction of San Luis Reservoir. Flows today range from 0 - 141.5 m^3/s in the primary channel and from 0 - 3.5 m^3/s in the secondary channel depending for the most part on the number of pumps in operation. One consequence of year-round pumping at relatively high rates is that the louver system is believed to be operating less efficiently than originally designed. Louver efficiency is unknown for the most of the 35 fish species that pass through the TFCF.

Flow hydraulics and presumably louver efficiency at the TFCF are strongly influenced by tides although the action is somewhat modified due to distance from the Pacific Ocean and effects of the many water diversions. Tidal action may change the water depth in the primary channel from 4.3 - 6.4 m during one cycle.

The purpose of our investigation was to begin to re-evaluate the efficiency of the louver system (defined as the success of the system at diverting fish into the holding tanks) under current operating conditions (i.e, higher flow, velocity, and debris accumulations).

METHODS

The experiments were conducted at the TFCF in 1993. Chinook salmon were released on April 14 - 15, May 12 - 13, and 25 - 26, and striped bass on September 28 - 29 and November 16 - 17. The general procedure was to release marked fish at sites up and downstream of the louvers and trash-rack, and to monitor their appearance (recovery) within the collection/holding tanks for two to five hours following their release. We tested the efficiency of the primary and secondary louver systems simultaneously.

Juvenile hatchery chinook salmon obtained from the Mokelumne River Fish Installation (Clements, California) were used in the April and May experiments. A random sampling of the recovered salmon indicated the fish averaged about 74.3 mm total length, TL, (N = 102, range: 58 - 90 mm TL) in April, 94.0 mm TL (N = 1,112 measured, range: 67 - 117 mm TL) May 12 - 13, and 97.5 mm TL (N = 755, range: 71 - 127 mm TL) May 25 - 26.

Hatchery striped bass fingerings obtained from the Fishery (Galt, California) were used in the September and November experiments. Some wild striped bass were also used in September. The wild fish were slightly larger (N = 177 measured; $\bar{x}$ = 119.2 mm TL, range 81 - 163 mm TL) than the hatchery fish (N = 1,169 measured; $\bar{x}$ = 99.7 mm TL, range 73 - 162 mm TL) in September. We did not measure fish prior to release in the April, May, or September experiments to minimize stress from handling and because the fish were the same year class and about the same size. However, we had two year classes in November and thus, we measured all fish prior to release. The November study fish averaged 166.7 mm TL (N = 1,711, range: 53 - 288 mm TL).

The hatchery fish were transported to the TFCF the morning preceding each pair of releases. The fish were transported in cooled, aerated water (about 11.1 °C for the salmon; about 12.8 °C for the striped bass) in a 378.5 liter tank where they awaited handling. All of hatchery fish appeared to be relatively healthy in that there were no external signs of disease or stress.

The fish were anesthetized in small batches using about 130 mg/l concentration of tricaine methanesulfonate, and given one of several unique fin-clips (upper lobe of the caudal fin, lower lobe of the caudal fin, anal fin, dorsal fin, left pectoral fin, right pectoral fin). Following placement of the fin-clip, the experimental fish were counted into separate compartments in a 1,893 liter rectangular tank containing cooled (11 - 13 °C), aerated water. A second series of fish, the control fish, were randomly removed during the fin-clipping process so that we could determine whether transport and handling might have impacted their survival. These fish were held for three to six hours in cooled (11.1 °C), aerated water in a 1,893 liter tub and their status (alive, dead, visibly stressed) then recorded. We were primarily concerned in noting whether the control fish exhibited obvious signs of stress from handling. We did not designate a control group of fish in the November experiments.

The temperature of the holding tank was gradually increased prior to release to approximate the temperature of the river water. We used aerators to keep the fish oxygenated during the holding period. The experimental fish were released at one of six sites (downstream of the trash-boom, in the primary channel on the downstream side of trash-rack, in the secondary channel upstream of both louvers, between the secondary louvers, in the secondary channel behind the louvers and in front of the sieve net, and directly into the holding tank; Figure 2). The fish were lowered to the water in buckets and evenly distributed along the surface. We removed any obviously stressed fish prior to release.

The release schedule occurred as follows: April 14 - fish released at 1330 hrs during the later stages of a flood cycle; April 15 - fish released at 1000 hrs during the later stages of an ebb cycle; May 12 - fish released at 1200 hrs during the later stages of a flood cycle; May 13 - fish released at 1200 hrs during the later stages of a flood cycle; May 25 - fish released at 2110 hrs pm about three hours into a flood cycle; May 26 - fish released at 2110 hrs about two hours into a flood cycle; September 28 - fish released at 1900 hrs toward the end of a flood cycle; September 29 - fish released at 1400 hrs during an ebb tide/slack water period; November 16 - fish released at 1545 hrs during an ebb tide/slack water period; November 17 - the first release occurred at 1100 hrs during a flood tide/slack water period; the second released occurred at 1415 hrs about three hours into an ebb cycle; the third release occurred at 1830 hrs about two hours into a flood cycle (Table 1).

The collection/holding tank system was continuous for two - five hours following each release (i.e., recovery was discontinued when few or no experimental fish appeared in the holding tank; Table 1). The collecting tank was drained at one hour intervals (at which time inflows switched to another tank) and all fish were identified, enumerated, and experimental fish examined for location of the fin-clip.

The trash-rack and louvers were relatively debris-free for the April and May 12 - 13 releases. However, large amounts of aquatic vegetation are typically drawn into the facility in the summer and fall and the remainder of releases were conducted during suboptimal but typical conditions. Specifically, the louvers and trash-rack were partially clogged during the

May 25 - 26 and September 28 - 29 experiments. On November 16, only the secondary louvers had been cleaned prior to release. On November 17th, conditions ranged from debris- laden for the 1100 hrs release, to being cleaned during the 1415 hrs release, to debris-free conditions for the 1830 hrs release.

Tide stage at each experimental release was determined for the Grant Line Canal station as reported in the 1993 Tidelog[R] (Northern California; see Table 1). However, the tide characterizations in Table 1 are approximations because of the distance between the Grant Line Canal station and the TFCF, and the effect of export operations, etc. on tide stage and height with distance from the ocean. Flood tide refers to the period during an incoming tide. Ebb tide refers to the period of time during an outgoing tide. Slack tide refers to the period of time during the changing of the tide.

Water velocity measurements were taken at several sites within the fish facility following release of the fish. A Marsh-McBirney velocity meter was used in combination with a weighted plate and guide wire so that the probe could be held in place at known points on the louver face. Measurements were taken on the upstream side of the louvers at 0.2 and 0.6 the depth from the water surface, on the downstream side of the trash-rack, and downstream of the secondary louvers (Figure 2).

We placed a sieve net (12.7 mm bar-mesh, 5.5 m in length, live well at the cod end) downstream of the secondary louvers to determine fish loss through the secondary louvers, and to evaluate the potential of using the net to aid in salvage efforts. Hatchery fish were released in the secondary channel downstream of the louvers during each experiment so that we could evaluate whether fish were able to find refuge within the secondary channel. The net was fished at one - two hour intervals following each experimental release and all captured fish were identified, enumerated, and measured.

Data Analysis

Louver efficiency was estimated using holding tank recoveries obtained during the three hours following release (a two hour recovery period was used following the 1830 hr release on November 17). We first determined the ratio of recovered fish to fish released directly into the holding tanks to determine if fish could escape from the holding tanks (they may find temporary refuge in the inlet pipes to each tank). We then estimated the efficiency of the secondary louver system by correcting the ratio of number recovered to number released by the calculated "holding tank efficiency" for each experiment (i.e., secondary louver efficiency = number of fish recovered in the holding tanks/(number of fish released into the secondary channel upstream of the secondary louvers X holding tank efficiency)).

We were unable to directly test primary louver efficiency because we could not collect fish slipping through the primary louvers. Thus, the efficiency of the primary louver system was estimated using the calculated secondary louver system efficiency for each experiment (primary louver efficiency = number of fish recovered in the holding tanks/(number of fish released in the primary channel at the trash-rack X estimated secondary louver efficiency)). Finally, an overall louver system efficiency was determined from the product of the estimated primary and secondary system efficiencies.

Fish released between the secondary louvers were not used to estimate secondary louver efficiency because the fish were subjected to a unique set of hydraulic conditions. These experiments were conducted so that we could determine whether fish respond similarly to one louver array as two arrays.

RESULTS

Juvenile Chinook Salmon

April 14 - 15

A total of 1,895 juvenile chinook salmon were released on 14 - 15 April: 1,290 fish upstream of the primary and secondary louvers, 355 fish between the secondary louvers, 100 fish downstream of the secondary louvers, and 150 fish into the holding tanks (Tables 2, 3). Water flow in the primary channel ranged from 97.0 - 110.8 m^3/s with velocities averaging 0.7 - 0.8 m/s in the primary channel and 0.6 - 0.7 m/s in the secondary channel (Table 4). Fish were released at 1330 hrs on the 14th during the flood tide (Table 1). On the 15th, we released fish at 1000 hrs toward the end of the ebb tide. Water temperatures ranged from 14 - 17 °C (Table 4).

Most of the fish released directly into the holding tanks were recovered both days (94.0 - 99.0% recovery; Tables 2,3). Estimated secondary louver efficiency was relatively high during both the high tide (72.3%) and low tide (100%) experiments (Table 5). The estimated primary louver efficiency was also high during the high tide release (82.4%), but fewer fish were recovered during the low tide - slack tide experiment (46.7%; Table 5). Overall louver efficiency ranged from 46.7% (ebb-slack tide experiment - 15th) to 59.6% (flood tide experiment - 14th).

Most of the recaptured fish were recovered during the first two hours following release for both experiments. However, very few experimental fish were louvered into the holding tanks following the first hour of recovery for the ebb tide release. About 45% of the fish released upstream of the primary louvers were unaccounted for during the 15th release as compared to about 32% for the 14th release (i.e., these fish were not louvered into the holding tanks nor were they collected in the secondary channel sieve net; Tables 2, 3).

Most of the fish released between the secondary louvers were recovered in the holding tanks both days (84 - 85% recovery), however, 6% of those released on the 14th were unaccounted for (either found some refuge within the secondary channel or slipped through during the five - ten minute period the net was out of the water for fish removal).

May 12 - 13

A total of 2,306 chinook salmon were released on 12 - 13 May: 1,498 fish were released upstream of the primary and secondary louvers, 502 between the secondary louvers, 106 downstream of the secondary louvers, and 200 fish directly into the holding tanks (Tables 6, 7). Flows in the primary channel were about 22.2 m^3/s with velocities averaging 0.1 m/s in the primary channel and 0.7 m/s in the secondary channel (Table 4). Release conditions were similar between the May 12 and May 13 releases; fish were released both days at 1200 hrs near the height of the flood tide (Table 1). Water temperature was 17 °C (Table 4). The fish released on the 12th appeared to be somewhat stressed at release, and thus, the fish were held with greater aeration and were more gradually acclimated to the river temperature prior to release on the 13th.

Of the fish released directly into the holding tank, all (100%) were recovered on the 12th and 98% were recovered on the 13th (2 fish were unaccounted for; Table 7). The secondary louvers were highly efficient and louvered about 95 - 96% of the fish released directly upstream both days (Table 5). In contrast, most of the fish (75 - 96%) released at the trash-boom and in the primary channel were not recovered after at least five hours of recovery. Estimated primary louver efficiencies ranged from 12.7% (12th) to 25.3% (13th) for overall louver efficiencies of 12% (12th) and 24.4% (13th; Table 5). As before, many of the fish that were recovered in the holding tanks were louvered during the first 1 - 2 hours following release.

Releases between the secondary louvers were continued although we had trouble getting healthy fish into the water. Fish released on the 12th were somewhat stressed but about 70% were recovered in the holding tanks (Table 6). Fish were handled more carefully on the 13th and 87.7% were louvered into the holding tank (Table 7).

May 25 - 26

We began nighttime releases and attempted to keep conditions similar between the two experiments. Flows were 78.2 - 78.5 m^3/s with velocities averaging 0.6 m/s in the primary and 0.7 m/s in the secondary channel (Table 4). Water temperature was 19 °C. The fish were released at 2110 hours both days about mid-way into the flood tide (Table 1). The trash-rack and part of the primary louvers were cleaned just prior to release.

A total of 2,116 chinook salmon were released on 25 - 26 May (Tables 8, 9). Some fish were visibly stressed prior to release, particularly on the 25th, presumably due to inadequate aeration and warm holding water temperatures. We increased the aeration and cooled the temperature of the holding water for the second release (26th) and the fish were clearly in better condition.

All (100%) of the 202 fish released into the holding tanks were recovered (Table 6). The secondary louvers were highly efficient at diverting the fish both days (88.3% - 92.9%; Table 5). Estimated primary louver efficiencies for fish released into the primary channel were also relatively high (75.1% on the 25th and 77.3% on the 26th; Table 5). Interestingly, more fish from the group released at the trash-boom were recovered in the holding tanks than fish released into the primary channel (estimated primary louver efficiency for the trash-boom fish was 83.8% on the 25th and 81.2% on the 26th). Overall louver efficiency for the two salmon releases was 66.3% on the 25th and 71.8% on the 26th. Most fish were recovered during the first hour following release.

A total of 400 fish were released between the secondary louvers (Tables 8, 9). The fish were visibly stressed on the 25th and only 25.2% were louvered into the holding tanks. Most were washed through the louvers into the sieve net. The fish were in better condition for the 26th release and about 81% were recovered in the holding tanks (Table 9). About 5 - 6% of the fish were unaccounted for on both days.

There were no obvious signs of stress or mortality in control fish held for at least five hours following handling in the April (N = 122), May 12 - 13 (N = 189), and May 25 - 26 (N = 194) experiments.

Juvenile Striped Bass

September 28 - 29

Both wild and hatchery juvenile striped bass were used in these experiments. The wild fish had been removed from the secondary channel the preceding day and held overnight. Fish were released at 1900 hrs during the height of the flood tide on the 28th, and at 1400 hrs on the 29th during the slack tide period preceding the next incoming cycle (Table 1). Flows in the primary channel ranged from 122.6 - 123.3 m^3/s; Table 4). Water velocity averaged 0.9 - 1.1 m/s in the primary channel and 0.7 m/s in the secondary channel. Water temperature was 21° C. There was a moderate amount of debris (hyacinth and pondweed) in the system that partially clogged the trash-rack and louvers during the experiments. Water hyacinth had begun to appear in masses at the fish facility where it caused some head loss at the trash-rack and louvers during the recovery period.

A total of 638 fish (425 hatchery, 213 wild) were released upstream of the primary and secondary louvers on the 28th (flood tide experiment; Table 10). All fish released directly into the holding tank were recovered (100%). The wild striped bass were mildly stressed prior to release but were louvered relatively efficiently (estimated primary louver efficiency of 83.5% and secondary louver efficiency of 75.5% for overall louver efficiency of 63.0%; Table 11). In contrast, overall louver efficiency (44.2%) was slightly lower for the hatchery fish (Tables 10, 11). More hatchery fish were recovered from the secondary channel release (89.9% efficiency) but fewer from the primary channel release (estimated primary louver efficiency of 49.2%).

Only hatchery fish were released on the 29th (slack tide experiment; Table 12). All fish (100%) released into the holding tank were recovered, but recoveries of fish from the other release sites were relatively low. Estimated secondary (79.2%), primary (40.4%), and overall (32.0%) louver efficiencies were lower than the preceding flood tide experiment (Table 11).

Hatchery striped bass were released between the secondary louvers both days, but more fish from the 28th release (86.2%) were louvered into the holding tanks than fish from the 29th release (50.5%). About 25% of the fish released on the 29th were unaccounted for in the holding tank and sieve net collections (Table 12).

There were no mortalities in control fish (N = 140) held for three hours.

November 16 - 17

A total of four releases were conducted on November 16 - 17 (Tables 13, 14). Flows were high and averaged 120.4 m^3/s (Table 4). Water temperature was cooler than the previous experiments and averaged 14 °C. Water hyacinth completely covered the water surface for two-three hundred meters in front of the fish facility and together with other plant material, clogged the trash-rack and louvers such that there was about a 0.5 - 1 meter differential in water surface elevation at the trash-rack and louvers throughout much of the two-day period.

Fish were released in the afternoon on the 16th during the slack tide period preceding onset of the flood cycle. The secondary louvers had been cleaned prior to release but the trash-rack and primary louvers remained clogged. Water velocity averaged 0.8 m/s in both the primary and secondary channels although flows were more variable in the primary channel (Table 4). No fish were released directly into the holding tanks, and we assumed a holding tank recovery of 100% as obtained in the September experiments. Overall louver efficiency of 504 striped bass juveniles released upstream of the primary and secondary louvers was 75.9% (82.6% for the secondary system, 91.9% efficiency for the primary system; Tables 11, 13). Fewer trash-boom fish were recovered in the holding tanks as compared to fish released into the primary channel (54% vs 76%).

Three releases were conducted on the 17th that spanned a range of tide and debris conditions. The first release of 350 fish occurred at 1100 hrs during the slack tide preceding the next ebb tide event (Tables 1, 14). The first release was conducted without any louver cleaning and all fish screens were heavily clogged. Water velocities were similar between the two louver channels; mean velocity of 0.8 m/s in the primary channel and 0.7 m/s in the secondary channel (Table 4). The secondary louvers were less efficient at diverting fish (44.3%) than the primary louvers (estimated primary louver efficiency 91.4%) and overall louver efficiency was relatively low (40.5%; Tables 11, 14). More fish were recovered from the group released at the trash-boom than either the primary or secondary channel lots (Table 14).

We conducted the second experiment while the primary louvers were being cleaned. A total of 352 fish were released at 1415 hrs on the ebb tide (Tables 1, 14). Both the trash-rack and secondary louvers were clogged with debris. Water velocities in the primary channel (mean velocity of 1.0 m/s) exceeded those in the secondary channel (0.4 m/s; Table 4).

Conditions during the second release were poor for diverting fish because the primary louver bay was being cleaned during most of the recovery period (during this process there was a sequential 2.4 m gap in the louver array as each plate was lifted for cleaning. In addition, flows entering a particular bypass were temporarily discontinued for the period of time while the associated nine louver sections were being cleaned. The secondary louvers diverted only about 30% of the experimental fish while none (0%) of the fish released into the primary channel were recovered (Tables 11, 14). Overall estimated efficiency was consequently 0% for this experiment (Tables 11, 14). A few (3.2%) fish from the trash-boom release were louvered into the holding tanks.

The third release was timed to occur after all the trash-rack and louvers had been cleaned. The fish (N=468) were released at 1830 hrs on the flood tide (Tables 1, 14). Water velocity in the primary channel again exceeded that in the secondary channel (Table 4). Louver efficiencies were high (estimated secondary efficiency of 90.1%; estimated primary efficiency of 95.8) as indicated by an overall system efficiency of 86.4% (Table 11). Most of the fish were louvered into the holding tanks within the first hour following release. The fish released at the trash-boom responded similarly to the louvers as had the fish released directly into the primary channel (Table 11). All (100%) of the fish released between the secondary louvers were recovered in the holding tanks (Table 14).

Sieve Net Experiments

Fish were released in the secondary channel downstream of the louvers in each experiment (Tables 2, 3, 6-10, 12-14). As regards the salmon experiments, most (> 90.0%) fish were recovered in the sieve net (Tables 2, 3, 6-9). Some fish (5-10%) were unaccounted for in the April and May 12 - 13 experiments and one fish from the May 12 experiment was recovered in the holding tank.

Fewer striped bass were recovered from the downstream secondary channel releases (68 - 87%; Tables 10, 12-14). Numbers of unaccounted fish ranged from 10% on November 17th to 29% on September 29th (some fish were unaccounted for in all experiments). One fish from each of the two September releases was recovered in the holding tanks.

DISCUSSION

Louvers are one type of fish exclusion system that is used to divert fish from flow (louver studies reviewed in Bell 1990; EPRI 1986; Odenweller and Brown 1982). The louver concept was first designed and tested at the site of the present Tracy Fish Collection Facility, and its effectiveness (i.e., the ability to divert fish from flow) was based on the premise that fish will move to avoid the turbulence created by the louvers. As a result, the fish can be guided into a bypass/collection system. The angle of the louvers at the TFCF sustains a sweeping flow across the louver face that also helps to guide entrained material to the bypass intakes. Louvers are considered effective at diverting fish from flow for fish large enough to avoid them (Bates et al. 1960; Mecum 1980; Vogel et al. 1988). However, louver efficiencies rarely approximate 100% because of many varied influences including fish size and shape, swimming ability, fish behavior, approach velocities (and whether the flow is uniform or not), tides, and debris loading.

Our experiments were intended to take a preliminary look at louver efficiencies under current operating conditions. Consequently, fish were released during periods of high and low export pumping (i.e., 22.1 - 123.3 m^3/s or 1 to 5 pumps in operation), high and low velocity conditions (0.1 - 1.7 m/s), ebb, flood, and slack tide events, periods of high and low debris loading, day and night, and during cleaning operations. Although we ran only 12 tests, we believe that all the above factors directly influenced louver efficiency at the CVP fish facility.

Of fish released immediately upstream of the primary and secondary louvers, slightly fewer striped bass were louvered into the holding tanks (56.2% of 1,972 fish) as compared to the chinook salmon (66.9% of 2,750 fish). This may have been due to several factors including the higher velocities and greater debris loads (including cleaning of the primary louver wall) experienced during the striped bass experiments. In addition, the striped bass were somewhat larger (53 - 288 mm; $\bar{x}$ = 136.6 mm) than the chinook salmon (58 - 127 mm; $\bar{x}$ = 91.6 mm) which may have enabled them to either find refuge or to move away (up or downstream of the louvers) and avoid the bypass-collection system.

The estimates of overall louver efficiency (i.e., primary X secondary louver efficiencies) were similar for the two groups of fish (chinook salmon: $\bar{x}$ = 46.8%, range 12 - 71.8%; striped bass: $\bar{x}$ = 47.6%, 0 - 77.8%; Tables 5, 11). Efficiency of the secondary system was consistently high (72 - 100%) except when the system was overloaded with vegetation debris in November. The November 17th experiments suggested that guidance efficiency in the secondary channel is directly influenced by debris load on the louver face (Table 11, 30 vs 90% efficiency). Efficiency of the primary louver system was more variable (0 - 96%) as might be expected because of the greater influence of flows, tides, and velocity in the primary channel. The secondary louver efficiencies estimates are possibly more accurate than the primary louver estimates because they were calculated directly from the proportion of recovered to released fish (as corrected by our ability to recover fish from the holding tanks). In contrast, the primary louver estimates were obtained indirectly (using the secondary system efficiency), and in reality are probably higher than we found.

Most fish that were unaccounted for were released either at the trash boom or in the primary channel and they had greater opportunity to move out of the facility, be swept through the primary louver slats, or lost to predation. Some fish were able to find refuge within both the primary and secondary channels for several hours following release. This would have reduced our estimate of immediate louver efficiency but would not be detrimental if the fish eventually were louvered into the holding tanks. In addition, as observed in the November 17th 1415 hrs experiment, primary louver efficiency (and thus overall louver efficiency) may dramatically drop to 0% during times when the primary louvers are lifted for cleaning. The fish that were unaccounted for from the holding tank releases may have moved into the inlets to the tanks.

Studies conducted at other louver facilities in California (e.g., John F. Skinner Delta Fish Protection Facility and the Tehama-Colusa Canal Fish Facility) noted overall efficiencies ranging from 50 - 95% with the lower efficiencies pertaining to smaller fish passing through the system (Skinner 1974; Heubach and Skinner 1978; Vogel et al. 1988). Efficiencies noted at the TFCF are similar to these estimates, even though the facilities are configured differently and are faced with a different array of confounding factors.

Our louver efficiency estimates are slightly lower than those previously reported for the TFCF. Specifically, Bates et al. (1960) found that the secondary system was relatively efficient (about 90%) for young chinook salmon and striped bass > 38mm in length, while Hallock et al. (1968) reported a primary system efficiency of about 85% for similar sized fish. Thus, the combined information from these two studies suggests an overall system efficiency of about 77% (i.e., 90% x 85%). However, our experiments probably more accurately describe current conditions at the TFCF because they were conducted during the typical operation and maintenance schedule (i.e., the louvers ranged from being completely debris-laden, to being lifted out of the water for cleaning, to being debris-free). In addition, the system today is deluged with large quantities of bulky aquatic vegetation, particularly water hyacinth and pond weeds, in contrast to the presence of small amounts of finer peat fibers in the early years of operation and testing.

The louver efficiencies reported here were influenced by many factors including pumping rates, debris load, cleaning operations, predation, and release of fish during sub-optimal, but typical, pumping operations. For example, one pair of salmon experiments were conducted during low flow periods (and consequently low primary channel velocities, see May 12 - 13 experiments), and we suspect that many of the salmon released upstream of the primary louvers either left the facility or moved downstream through the louvers. In addition, predation may have been a factor in all of the salmon experiments as indicated by the removal of eight experimental fish (62 - 93 mm TL) from a 400 mm TL striped bass collected in the holding tank during the April 14 experiment. The May 25 - 26 experiments suggest that salmon may be better louvered at night (as compared to the April 14 - 15 and May 12 - 13 experiments), however, we did not examine this in depth. As regards the striped bass experiments, all were conducted during periods of increasing debris-load and relatively high flow and velocity conditions. Either clogged louvers or high velocities could act to reduce louver efficiency for this species, but these are the typical conditions during which juvenile striped bass are drawn into the facility today. The lowest recovery rate was noted in the striped bass experiment conducted during the primary louver cleaning process in November. A new louver cleaning machine is currently being tested at the TFCF to try to reduce the need to lift the louver plates for cleaning.

The louver efficiencies were no doubt influenced by the higher velocities present in the system today. The secondary channel velocities generally exceeded those in the primary channel at low flows (e.g., May 12 - 13 and May 25 - 26 experiments) whereas primary channel velocities were higher during high flow experiments (e.g. April, September, and November experiments; Tables 4, 5, 11). These data suggest that the recommended bypass ratio of 1 - 1.4 (bypass velocity to approach velocity; Bates et al. 1960; Mecum 1980) may not have been achieved during high flow periods. We also observed areas of eddying or negative flow patterns on both walls of the primary channel during certain flow conditions and noted that there was not a uniform velocity approaching the primary louver.

Operating criteria for the TFCF recommends that velocities of 0.9 - 1.1 m/s be maintained in the winter and spring to encourage chinook salmon smolts into the bypasses, while a velocity of 0.3 m/s (maximum of 0.7 m/s) be maintained in late spring through early fall to aid deflection of juvenile striped bass. The velocities we observed during the salmon experiments were generally lower than the above recommendation while those observed during the striped bass releases were higher (Table 3). However, the relatively high louver efficiencies obtained in some of the experiments suggests that the influence of velocity on louver efficiency is complex and not well understood or described at the TFCF.

Fish condition may also have influenced the louver efficiencies as suggested by visible signs of stress in some fish (noted when the fish were held in crowded conditions without adequate aeration and water temperature). We removed all fish that appeared to be in distress prior to release, but presume that some of the released fish may have been disoriented upon introduction to the river water. The salmon experiments were conducted in the spring because water temperatures were cool and because salmon were normally passing through the system at that time. We switched to striped bass in the fall for the same reasons. None of the control fish exhibited any external signs of stress from fin-clipping and handling and we assume that the study fish recovered from these procedures prior to release. We also assumed that the fin-clips did not affect swimming ability or thus, louver efficiency, but realize that some fish may have been impaired.

The experiments in which fish were released between the double set of secondary louvers were difficult to conduct and provided mixed results. We do not feel that we adequately tested the efficiency of the second louver array to louver fish as the study fish had little time to regain their orientation before being faced with the louvers. Many of the fish were observed to be somewhat stressed upon release and appeared to either get caught in the flow heading toward the bypass opening, or to get washed through the louver wall. However, some fish, particularly the striped bass, apparently were able to recover as up to 25% were unaccounted for in some experiments.

The sieve net experiments (i.e., testing our ability to recover fish that had slipped through the secondary louver slats) suggest that the sieve net was successful in capturing most (> 90% of the salmon, 70-87% of the striped bass) of the fish released in the secondary channel downstream of the louvers. Some fish (more striped bass than salmon) were observed in the eddying flow created by the base of the net and avoided capture.

CONCLUSIONS AND RECOMMENDATIONS

The TFCF began operation in 1957 after several years of on-site extensive fish screen testing by Bureau of Reclamation, Fish and Wildlife Service, and California Department of Fish and Game (Bates and Visonhaler 1956; Rhone and Bates 1960). Louver efficiency tests conducted in the 1950's, 1960's and 1970's at the state and federal fish screen facilities indicated that louvers were relatively efficient for screening juvenile striped bass and chinook salmon as long as approach velocities were kept low, and primary bypass velocities exceeded approach velocities by a factor of 1 to 1.4. However, there is increasing concern that the louver system may not be performing as well as intended because of problems with maintaining recommended approach and bypass velocities, because of heavy debris loads, and because louver efficiency is unknown for many of the Delta species salvaged at the TFCF.

The relationship between louver efficiency, flows, velocities, tides, and debris loads is complex and we can not clearly state which factor more strongly influences performance of the primary system. However, efficiencies were lowest during the experiments conducted during low flow/low velocity conditions, and when the louver screens were clogged or out of the water for cleaning.

The system was variably efficient for each species. The best results for chinook salmon were obtained with moderately high flows and velocities during an incoming tide in the evening (Table 5). The least number of salmon were recovered during periods of low flows and low velocities. However, if the unaccounted salmon moved upstream and out of the facility then these results are acceptable. As regards striped bass, efficiencies appeared to be directly related to the quantity of aquatic vegetation in the louver/bypass system (Table 11). All of the striped bass experiments were conducted under conditions of high flows and relatively high velocities and thus, we do not know how young striped bass may respond to different conditions. The lowest estimate of louver efficiency was obtained during the primary louver cleaning process and we presume that many of the fish slipped through the louver array and were lost to the intake channel. As mentioned above, this cleaning process has recently been modified so that the majority of the louver plates are cleaned in place.

The secondary louvers were generally more effective ($\bar{x}$ = 80.0%, range: 72% - 100% for chinook salmon and 30 - 90% for striped bass) than the primary louvers ($\bar{x}$ = 59.3%, range: 13% - 82% for chinook salmon and 0 - 96% for striped bass) at diverting fish from the flow. This occurred because louver efficiency of the primary bay is more vulnerable to the influences of pumping rate, tide, debris load, etc. Similar recovery rates of fish released at the trash-boom site and at the primary channel site suggest that the estimated primary louver efficiencies were representative for each set of tide, velocity and debris conditions. Efficiency of the secondary system was also more consistent than that of the primary louver bay, but efficiency of both systems was strongly influenced by debris load. The efficiencies reported here are somewhat lower than estimates reported by Bates et al. (1960) and Hallock et al. (1968) but are probably more reflective of the wide range of conditions that occur today at the TFCF.

We recommend the following:

- Determine levels of louver efficiency that are acceptable for the various key species including chinook salmon, Delta smelt, splittail, and striped bass.

- Continue to test louver efficiencies following installation of the flow/velocity measurement equipment and the experimental primary louver cleaner.

- Following installation of flow measurement equipment, Reclamation should describe the hydraulics of the system over a range of tide, flow, debris load, and state pumping conditions, and compare these data to the recommended approach and bypass velocities.

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LITERATURE CITED

Bates, D.W. and R. Vinsonhaler. 1956. Use of louvers for guiding fish. Trans. Amer. Fish. Soc. 86:39-57.

Bates, D.W., O. Logan, and E. Pesonen. 1960. Efficiency evaluation, Tracy Fish Collection Facility, Central Valley Project, California.

Bell, M.C. 1990. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps of Engineers. North Pacific Division, Portland, Oregon.

EPRI (Electric Power Research Institute). 1986. Assessment of downstream migrant fish protection technologies. Stone and Webster Engineering Corporation, Boston, Massachusetts.

Hallock, R.J., R.A. Iselin, and D.J. Fry, Jr. 1968. Efficiency tests of the primary louver system, Tracy Fish Screen 1966-67. Marine Resources Branch, Department of Fish and Game.

Heubach, W., and J. E. Skinner. 1978. 1973 Evaluation of the federal fish collecting facility at Tracy, California. California Department of Fish and Game.

Hiebert, S. 1995. Tracy Fish Collection Facility Studies, California, Continuous monitoring of fish eggs and larvae, 1991-1992. Volume 2. Bureau of Reclamation, Denver, Colorado.

Liston, C., C. Karp, L. Hess, and S. Hiebert. 1994. Summary of the fish predator removal program and intake channel studies, 1991-1992. Tracy Fish Collection Facility Studies, California, Volume 1. Bureau of Reclamation, Sacramento and Denver.

Mecum, W.L. 1980a. Recommended operations for the federal fish collection facility at Tracy, from June 1 to September 30. Bay-Delta Fishery Project, Report No. 77-4, California Department of Fish and Game.

Mecum, W.L. 1980b. The efficiency of various bypass configurations for juvenile striped bass Morone saxatilis, and American shad, Alosa sapidissima. Administrative Rpt No. 80-12, California Department Fish and Game.

Odenweller, D.B. and R.L. Brown. 1982. Delta fish facilities program report through June 30, 1982. Technical Report 6, Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary.

Rhone, T.J., and D.W. Bates. 1960. Fish protective facilities at the Tracy Pumping Plant-Central Valley Project, California. Ninth hydraulics division conference, American Society Civil Engineers, Seattle.

Skinner, J.E. 1974. A functional evaluation of a large louver screen installation and fish facilities research on California water diversion projects. In L.D. Jensen, Ed., Proceedings of the second entrainment and intake screening workshop. Johns Hopkins University, Baltimore, MD.

USDOI (U.S. Department of Interior). 1957. Fish protection at the Tracy Pumping Plant. Bureau of Reclamation and Fish and Wildlife Service. 96pp.

Vogel, D.A., K. R. Marine, and J.G. Smith. 1988. Fish passage action program for Red Bluff Diversion Dam. U.S. Fish and Wildlife Service. Red Bluff, California.

APPENDIX

Conversions from metric system to English system

millimeters (mm)	X	0.0394 = inches
kilometer (km)	X	0.625 = miles
meter (m)	X	3.281 = feet
cubic meter per second (m^3/s)	X	35.335 = cubic feet per second (cfs)
meter per second (m/s)	X	3.28 = feet per second (fps)
°C	X	(1.8)+32 = °F
liters (l)	X	0.264 = gallons

Table 1. Release and Recovery Schedule for Striped Bass and Chinook Salmon Louver Experiments, Tracy Fish Collection Facility, 1993.

Date	Number Fish Released	Time of Release	Tide Stage[1]	Recovery Period
		Chinook Salmon		
April 14	1,149	1330 hrs	Flood (High tide-1459 hrs)	5 hours
April 15	746	1000 hrs	Ebb (Low tide-1110 hrs)	5 hours
May 12	1,153	1200 hrs	Flood (High tide-1308 hrs)	5 hours
May 13	1,153	1200 hrs	Flood (High tide-1414 hrs)	5 hours
May 25	1,151	2110 hrs	Flood (High tide-0106 hrs)	5 hours
May 26	965	2110 hrs	Flood (High tide-0154 hrs)	3 hours
		Striped Bass		
September 28	942	1900 hrs	Flood (High tide-1955 hrs)	5 hours
September 29	1,555	1400 hrs	Slack (Low tide-1420 hrs)	4 hours
November 16	540	1545 hrs	Slack (Low tide-1537 hrs)	4 hours
November 17	350	1100 hrs	Slack (High tide-1121 hrs)	5 hours
November 17	352	1415 hrs	Ebb (Low tide-1635 hrs)	5 hours
November 17	468	1830 hrs	Flood (High tide-2154 hrs)	2 hours

[1] Tide stage at release. Number in parentheses is time of next tide cycle change as determined for Grant Line Canal Station, (Tidelog-Northern California).

Table 2. Summary of Mark-Recapture Experiments Using Juvenile Chinook Salmon at Six Release Sites on April 14, 1993, Tracy Fish Collection Facility. Numbers in parentheses are percent recovery.

	Trash-Boom	Primary Channel	Secondary Channel	Between Secondary Louvers	Sieve Net[1]	Holding Tank
No. Released	249	250	250	250	50	100
No. Recovered in Holding Tank after 3 hours[2]	120 (48.2)	149 (59.6)	179 (71.6)	210 (84.0)	--	99 (99.0)
No. Recovered in Sieve Net after 4 hours[3]	28 (11.2)	39 (15.6)	61 (24.4)	25 (10.0)	45 (90.0)	--
No. Unaccounted[4]	100 (40.2)	61 (24.4)	10 (4.0)	15 (6.0)	5 (10.0)	1 (1.0)

[1] Fish released in secondary channel downstream of the louvers.
[2] Includes 8 fish removed from a striped bass (2 trash-boom, 1 primary channel, 2 secondary channel, 2 between secondary louvers, and 1 holding tank release). Two additional fish (1 trash-boom, and 1 primary channel release) were recovered in subsequent collections.
[3] No additional fish were recovered after 5:30 pm.
[4] After a 6 hour recovery period.

Table 3. Summary of Mark-Recapture Experiments Using Juvenile Chinook Salmon at Six Release Sites on April 15, 1993, Tracy Fish Collection Facility. Numbers in parentheses are percent recovery.

	Trash-Boom	Primary Channel	Secondary Channel	Between Secondary Louvers	Sieve Net[1]	Holding Tank
No. Released	193	197	151	105	50	50
No. Recovered in Holding Tank after 3 hours[2]	96 (49.7)	92 (46.7)	143 (94.7)	89 (84.8)	1 (2.0)	47 (94.0)
No. Recovered in Sieve Net after 4 hours[3]	12 (6.2)	13 (6.6)	6 (4.0)	16 (15.2)	45 (90.0)	--
No. Unaccounted[4]	84 (43.5)	92 (46.7)	2 (1.3)	--	4 (8.0)	3 (6.0)

[1] Fish released in secondary channel downstream of the louvers.
[2] One additional fish (1 trash-boom release) was recovered in subsequent collections.
[3] No additional fish were recovered after 1:15 pm.
[4] After a 6 hour recovery period.

Table 4. Flow, Tide, Water Temperature, and Water Velocity Data During the Louver Experiments, Tracy Fish Collection Facility, 1993.

Date	Flow (m^3/s)	Tide[1]	Temperature (°C)	Velocity (m/s)[2] Primary Channel	Velocity (m/s)[2] Secondary Channel
April 14	97.0	Flood	14	0.70 (N=2; 0.70)	0.64 (N=4; 0.55-0.70)
April 15	110.8	Ebb	17	0.79 (N=3; 0.70-0.91)	0.73 (N=3; 0.61-0.82)
May 12	22.1	Flood	17	0.09 (N=34; 0.03-0.12)	0.70 (N=8; 0.55-0.88)
May 13	22.3	Flood	17	0.09 (N=47; 0.03-0.12)	0.70 (N=4; 0.70-0.82)
May 25	78.2	Flood	19	0.58 (N=55; 0.21-0.85)	0.67 (N=6; 0.54-0.76)
May 26	78.5	Flood	19	0.55 (N=56; 0.30-0.73)	0.67 (N=6; 0.54-0.76)
September 28	122.6	Flood	21	0.88 (N=17; 0.12-1.55)	0.70 (N=10; 0.46-0.85)
September 29	123.3	Slack	21	1.07 (N=28; 0.09-1.46)	0.73 (N=12; 0.67-0.79)
November 16	120.0	Slack	14	0.76 (N=20; 0.30-1.43)	0.82 (N=8; 0.67-0.94)
November 17 11:00 am	120.7	Slack	14	0.82 (N=2; 0.76-0.88)	0.70 (N=8; 0.43-0.94)
2:15 pm	120.7	Ebb	14	1.04 (N=17; 0.61-1.43)	0.43 (N=4; 0.37-0.52)
6:30 pm	120.7	Flood	14	1.09 (N=11; 0.76-1.71)	0.82 (N=4; 0.76-0.88)

[1] Tide determined for Grant Line Canal station, (Tidelog-Northern California).
[2] Parentheses contain number of observations and range of values.

Table 5. Summary of Physical Data and Estimated Louver Efficiencies for Chinook Salmon Louver Experiments, Tracy Fish Collection Facility, 1993.

Date	Total Length[1] (mm)	Flow (m^3/s)	Tide[2]	Velocity (m/s)[3]		Louver Efficiency		
				Primary Channel	Secondary Channel	Primary[4] Channel	Secondary[5] Channel	Overall[6] System
April 14	74.2 (N=316, 58-96)	97.0	Flood	0.70	0.64	82.4% (66.7%)	72.3%	59.6%
April 15		110.8	Ebb	0.79	0.73	46.7% (49.7%)	100%	46.7%
May 12	94.0 (N=1,112, 67-117)	22.1	Flood	0.09	0.70	12.7% (4.2%)	94.8%	12.0%
May 13		22.3	Flood	0.09	0.70	25.3% (6.6%)	96.3%	24.4%
May 25	97.4 (N=949, 68-127)	78.2	Flood	0.58	0.67	75.1% (83.8%)	88.3%	66.3%
May 26		78.5	Flood	0.55	0.67	77.3% (81.2%)	92.9%	71.8%

[1] Averaged for the two day experiment. Parentheses contains number of fish measured and size range.
[2] Tide stage at time of release (tide determined for Grant Line Canal Station, Tidelog-Northern California).
[3] Averaged for the 3 hour recovery period following release.
[4] Efficiencies were determined from: (the ratio of the number of fish recovered in the collection tanks to the number released in the primary channel) X (the estimated secondary louver efficiency). Number in parentheses is primary louver efficiency as estimated from the trash boom release.
[5] Efficiencies were determined from: (the ratio of the number of fish recovered in the collection tanks to the number released immediately upstream of the secondary louvers) X (holding tank efficiency).
[6] The overall louver efficiency as determined from the product of estimated primary and secondary louver efficiencies.

Table 6. Summary of Mark-Recapture Experiments Using Juvenile Chinook Salmon at Six Release Sites on May 12, 1993, Tracy Fish Collection Facility. Numbers in parentheses are percent recovery.

	Trash-Boom	Primary Channel	Secondary Channel	Between Secondary Louvers	Sieve Net[1]	Holding Tank
No. Released	249	250	249	249	56	100
No. Recovered in Holding Tank after 3 hours[2]	13 (5.2)	38 (15.2)	236 (94.8)	174 (69.9)	--	100 (100.0)
No. Recovered in Sieve Net after 4 hours[3]	3 (1.2)	11 (4.4)	10 (4.0)	74 (29.7)	54 (96.4)	--
No. Unaccounted[4]	226 (90.8)	183 (73.2)	1 (0.4)	1 (0.4)	2 (3.6)	--

[1] Fish released in secondary channel downstream of the louvers.
[2] Twenty-five additional fish (6 trash boom, 17 primary channel, 1 secondary channel, and 1 between secondary louver releases) were recovered in subsequent collections.
[3] Six additional fish (1 trash boom, 1 primary channel, 1 secondary channel, 1 between secondary louvers, and 2 sieve net releases) were recovered in subsequent collections.
[4] After a 20 hour recovery period.

Table 7. Summary of Mark-Recapture Experiments Using Juvenile Chinook Salmon at Six Release Sites on May 13, 1993, Tracy Fish Collection Facility. Numbers in parentheses are percent recovery.

	Trash-Boom	Primary Channel	Secondary Channel	Between Secondary Louvers	Sieve Net[1]	Holding Tank
No. Released	250	250	250	253	50	100
No. Recovered in Holding Tank after 3 hours[2]	16 (6.4)	61 (24.4)	236 (94.4)	222 (87.7)	--	98 (98.0)
No. Recovered in Sieve Net after 4 hours[3]	2 (0.8)	12 (4.8)	8 (3.2)	21 (8.3)	47 (94.0)	--
No. Unaccounted[4]	228 (91.2)	171 (68.4)	6 (2.4)	10 (3.9)	3 (6.0)	2 (2.0)

[1] Fish released in secondary channel downstream of the louvers.
[2] Eight additional fish (4 trash boom, and 4 primary channel releases) were recovered in subsequent collections.
[3] Two additional fish (2 primary channel releases) were recovered in subsequent collections.
[4] After a 5 hour recovery period.

Table 8. Summary of Nighttime Mark-Recapture Experiments Using Juvenile Chinook Salmon at Six Release Sites on May 25, 1993, Tracy Fish Collection Facility. Numbers in parentheses are percent recovery.

	Trash-Boom	Primary Channel	Secondary Channel	Between Secondary Louvers	Sieve Net[1]	Holding Tank
No. Released	254	250	247	250	49	101
No. Recovered in Holding Tank after 3 hours[2]	189 (74.4)	165 (66.0)	218 (88.3)	63 (25.2)	--	101 (100.0)
No. Recovered in Sieve Net after 4 hours[3]	20 (7.9)	3 (1.2)	19 (7.7)	172 (68.8)	49 (100.0)	--
No. Unaccounted[4]	45 (17.7)	81 (32.4)	10 (4.0)	12 (4.8)	--	--

[1] Fish released in secondary channel downstream of the louvers.
[2] Two additional fish (1 primary channel, 1 between secondary louvers) were recovered in subsequent collections.
[3] Two additional fish (2 between secondary louvers) were recovered in subsequent collections.
[4] After a 12 hour recovery period.

Table 9. Summary of Nighttime Mark-Recapture Experiments Using Juvenile Chinook Salmon at Six Release Sites on May 26, 1993, Tracy Fish Collection Facility. Numbers in parentheses are percent recovery.

	Trash-Boom	Primary Channel	Secondary Channel	Between Secondary Louvers	Sieve Net[1]	Holding Tank
No. Released	252	252	154	150	56	101
No. Recovered in Holding Tank after 3 hours[2]	190 (75.4)	181 (71.8)	143 (92.9)	121 (80.7)	--	101 (100.0)
No. Recovered in Sieve Net after 3 hours[2]	4 (1.6)	4 (1.6)	11 (7.1)	20 (13.3)	56 (100.0)	--
No. Unaccounted[3]	58 (23.0)	67 (26.6)	--	9 (6.0)	--	--

[1] Fish released in secondary channel downstream of the louvers.
[2] No recovery effort after the 3 hour follow-up period following release.
[3] After a 3 hour recovery period.

Table 10. Summary of Mark-Recapture Experiments Using Juvenile Striped Bass at Five Release Sites on September 28, 1993, Tracy Fish Collection Facility. Numbers in parentheses are percent recovery.

	Primary Channel		Secondary Channel		Between Secondary Louvers	Sieve Net[1]	Holding Tank
	Wild	Hatchery	Wild	Hatchery			
No. Released	111	226	102	199	203	50	51
No. Recovered in Holding Tank after 3 hours[2]	70 (63.1)	100 (44.2)	77 (75.5)	179 (89.9)	175 (86.2)	1 (2.0)	51 (100.0)
No. Recovered in Sieve Net after 3 hours[3]	1 (0.9)	3 (1.3)	5 (4.9)	8 (4.0)	11 (5.4)	34 (68.0)	--
No. Unaccounted[4]	40 (36.0)	123 (54.4)	15 (14.7)	8 (4.0)	15 (7.4)	12 (24.0)	--

[1] Fish released in secondary channel downstream of the louvers.
[2] Two additional fish (2 wild fish in the secondary channel) were recovered in subsequent collections.
[3] Twelve additional fish (3 wild and 4 hatchery fish released in the secondary channel; 2 fish from between the secondary louvers, and 3 sieve net releases) were recovered in subsequent collections.
[4] After a 5.5 hour recovery period.

Table 11. Summary of Physical Data and Estimated Louver Efficiencies for Striped Bass Louver Experiments, Tracy Fish Collection Facility, 1993.

Date	Total Length[1] (mm)	Flow (m^3/s)	Tide[2]	Velocity (m/s)[3] Primary Channel	Velocity (m/s)[3] Secondary Channel	Louver Efficiency Primary[4] Channel	Louver Efficiency Secondary[5] Channel	Louver Efficiency Overall[6] System
Sept 28	99.5	122.6	Flood	0.88	0.70			
Hatchery	(N=1,309, 73-162)					49.2%	89.9%	44.2%
Wild	(N=177, 81-163)					83.5%	75.5%	63.0%
Sept 29		123.3	Slack	1.07	0.73	40.4% (48.2%)	79.2%	32.0%
Nov 16	166.7 (N=1,711, 53-288)	120.0	Slack	0.76	0.82	91.9% (65.4%)	82.6%	75.9%
Nov 17[7]								
11:00 am		120.7	Slack	0.82	0.70	91.4	44.3	40.5%
2:15 pm		120.7	Ebb	1.04	0.43	0	29.6	0
6:30 pm		120.7	Flood	1.09	0.82	95.8% (95.9%)	90.1%	77.8%

[1] Averaged for the two day experiment. Parentheses contains number of fish measured and size range.
[2] Tide stage at time of release (tide determined for Grant Line Canal Station, Tidelog-Northern California).
[3] Averaged for the 3 hour recovery period following release.
[4] Efficiencies were determined from: (the ratio of the number of fish recovered in the collection tanks to the number released in the primary channel) X (the estimated secondary louver efficiency). Number in parentheses is primary louver efficiency as estimated from the trash-boom release.
[5] Efficiencies were determined from: (the ratio of the number of fish recovered in the collection tanks to the number released immediately upstream of the secondary louvers) X (holding tank efficiency).
[6] The overall louver efficiency as determined from the product of estimated primary and secondary louver efficiencies.
[7] Three experimental releases were conducted:
11:00 am release - trash-rack and secondary louver partially clean, primary louvers clogged,
2:15 pm release - primary louvers being cleaned throughout recovery period,
6:30 pm release - all louvers and trash-rack cleaned prior to release.

Table 12. Summary of Mark-Recapture Experiments Using Juvenile Striped Bass at Six Release Sites on September 29, 1993, Tracy Fish Collection Facility. Numbers in parentheses are percent recovery.

	Trash-Boom	Primary Channel	Secondary Channel	Between Secondary Louvers	Sieve Net[1]	Holding Tank
No. Release	626	431	192	198	56	52
No. Recovered in Holding Tank after 3 hours[2]	239 (38.2)	138 (32.0)	152 (79.2)	100 (50.5)	1 (1.8)	52 (100.0)
No. Recovered in Sieve Net after 4 hours[3]	15 (2.4)	4 (0.9)	3 (1.6)	44 (22.2)	39 (69.6)	--
No. Unaccounted[4]	371 (59.3)	288 (66.8)	36 (18.7)	50 (25.3)	16 (28.6)	--

[1] Fish released in secondary channel downstream of the louvers.
[2] Seven additional fish (1 trash-boom, 1 primary channel, 1 secondary channel, and 4 from between the secondary louvers release) were recovered in subsequent collections.
[3] No additional fish were recovered after the 4-hour follow-up period.
[4] After a 4 hour recovery period.

Table 13. Summary of Mark-Recapture Experiments Using Juvenile Striped Bass at Four Release Sites on November 16, 1993, Tracy Fish Collection Facility. Numbers in parentheses are percent recovery.

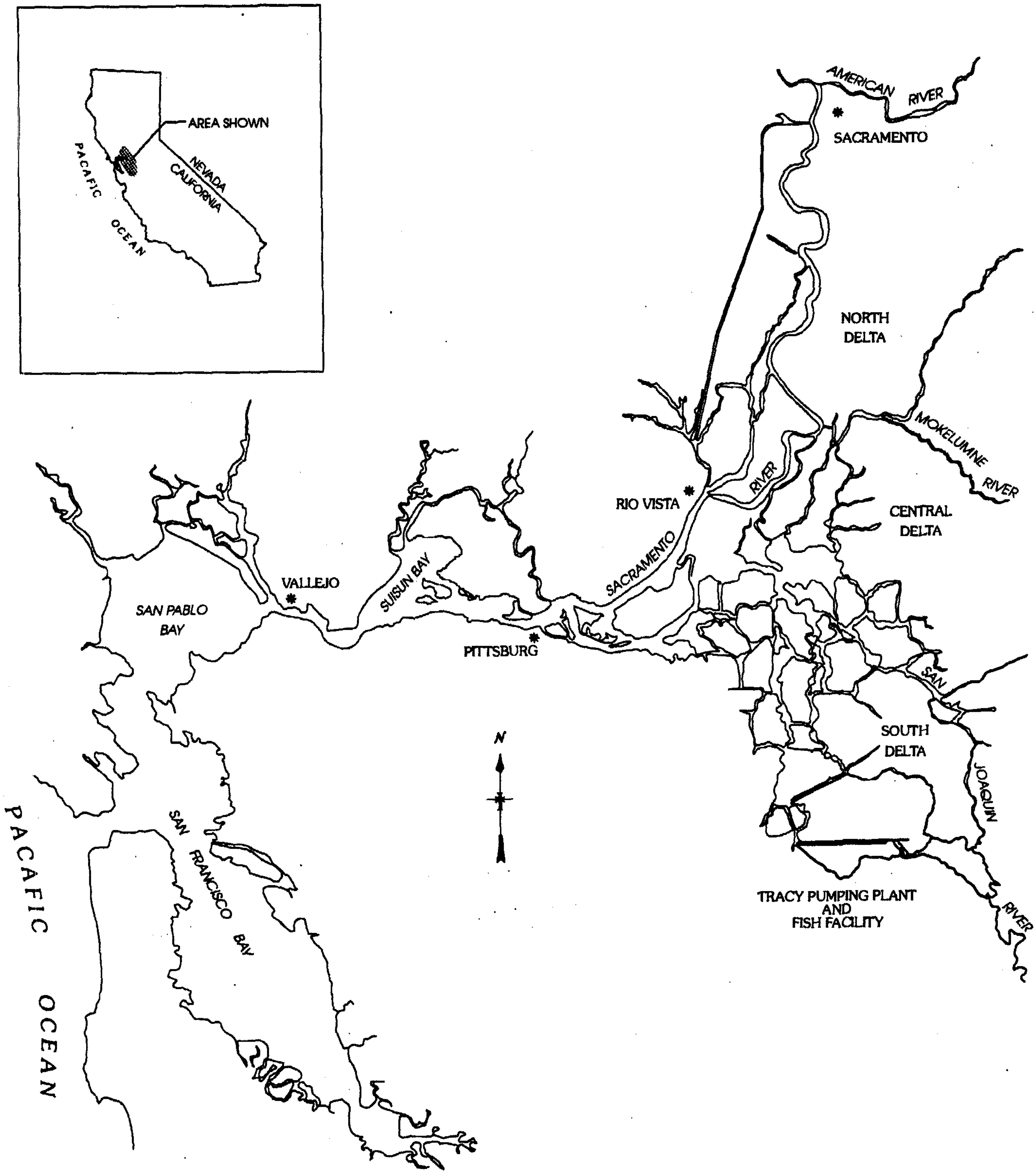
	Trash-Boom	Primary Channel	Secondary Channel	Sieve Net[1]
No. Released	198	191	115	36
No. Recovered in Holding Tank after 3 hours[2]	107 (54.0)	145 (75.9)	95 (82.6)	--
No. Recovered in Sieve Net after 4 hours[2]	6 (3.0)	3 (1.6)	5 (4.3)	27 (75.0)
No. Unaccounted[3]	85 (42.9)	43 (22.5)	15 (13.0)	9 (25.0)

[1] Fish released in secondary channel downstream of the louvers.
[2] No recovery effort after the 3-4 hour follow-up period following release.
[3] After a 4 hour recovery period.

Table 14. Summary of Mark-Recapture Experiments Using Juvenile Striped Bass at Five Release Sites on November 17, 1993, Tracy Fish Collection Facility. Numbers in parentheses are percent recovery.

	Trash Boom	Primary Channel	Secondary Channel	Between Secondary Louvers	Sieve Net[1]
		11:00 am Release			
No. Released	124	126	70	--	30
No. Recovered in Holding Tank after 3 hours[2]	71 (57.3)	51 (40.5)	31 (44.3)	--	--
No. Recovered in Sieve Net after 3 hours[3]	1 (0.8)	1 (0.8)	--	--	25 (83.3)
No. Unaccounted[4]	38 (30.6)	31 (24.6)	5 (7.1)	--	3 (10.0)
		2:15 pm Release			
No. Released	125	126	71	--	30
No. Recovered in Holding Tank after 3 hours[5]	4 (3.2)	--	21 (29.6)	--	--
No. Recovered in Sieve Net after 2 hours[6]	2 (1.6)	--	1 (1.4)	--	25 (83.3)
No. Unaccounted[7]	115 (92.0)	124 (98.4)	13 (18.3)	--	3 (10.0)
		6:30 pm Release			
No. Released	155	154	71	50	38
No. Recovered in Holding Tank after 2 hours[8]	134 (86.5)	133 (86.4)	64 (90.1)	50 (100.0)	--
No. Recovered in Sieve Net after 2 hours[8]	3 (1.9)	4 (2.6)	--	--	33 (86.8)
No. Unaccounted[9]	18 (11.6)	17 (11.0)	7 (9.8)	--	5 (13.2)

[1] Fish released in secondary channel downstream of the louvers.
[2] Eighty-five additional fish (13 trash-boom, 42 primary channel, and 30 secondary channel) were recovered in subsequent collections.
[3] Eight additional fish (1 trash boom, 1 primary channel, 4 secondary channel, and 2 sieve net releases) were recovered in subsequent collections.
[4] After a 9 hour recovery period.
[5] Thirty-six additional fish (4 trash-boom, 2 primary channel, and 30 secondary channel releases) were recovered in subsequent collections.
[6] Eight additional fish (6 secondary channel, and 2 sieve net release) were recovered in subsequent collections.
[7] After a 6 hour recovery period.
[8] No additional recovery effort after 8:30 pm.
[9] After a 2 hour recovery period.



Sacramento - San Joaquin Estuary

Figure 1.
Map of the Sacramento - San Joaquin Delta showing the location of the Tracy Fish Collection Facility

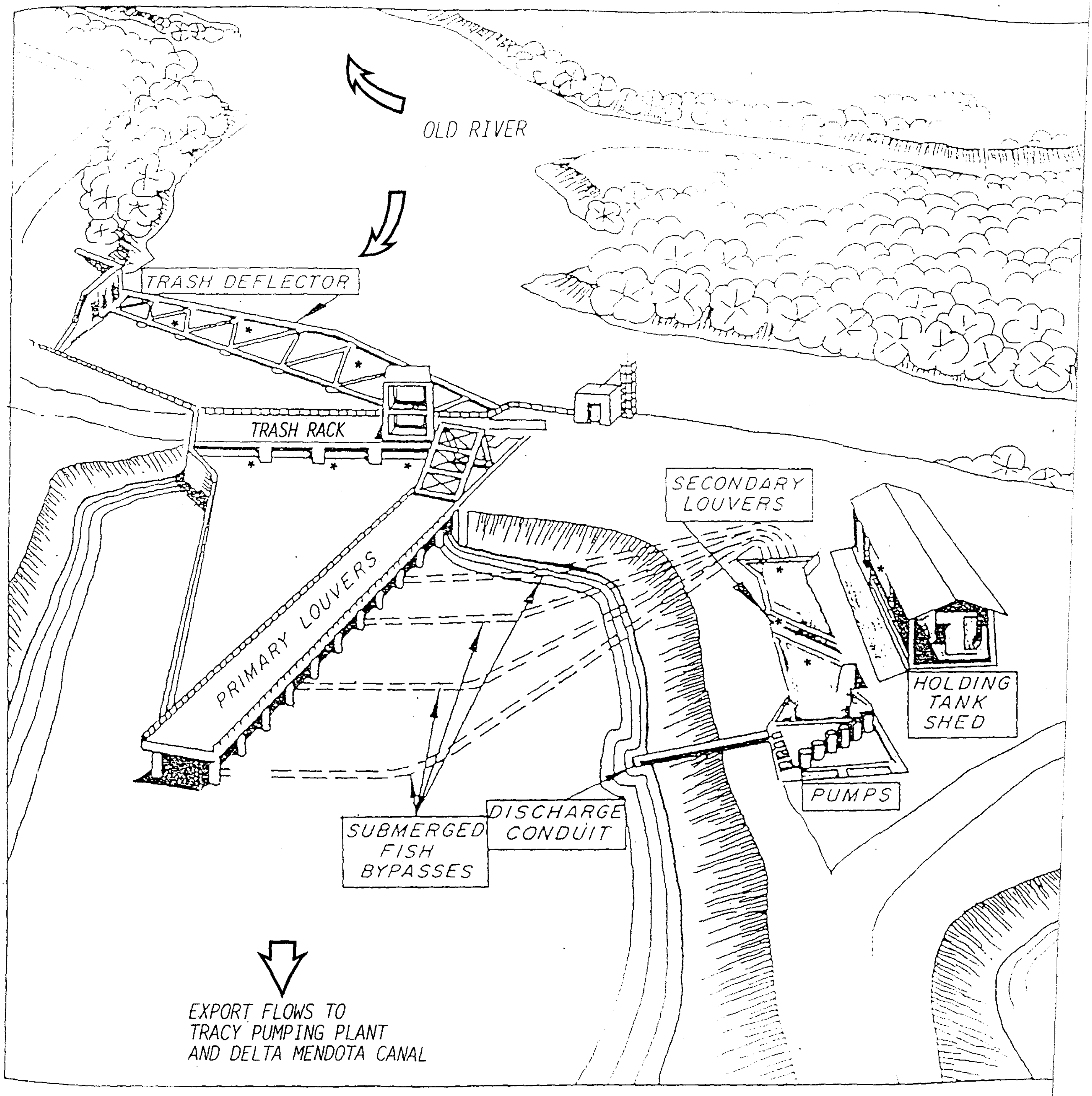
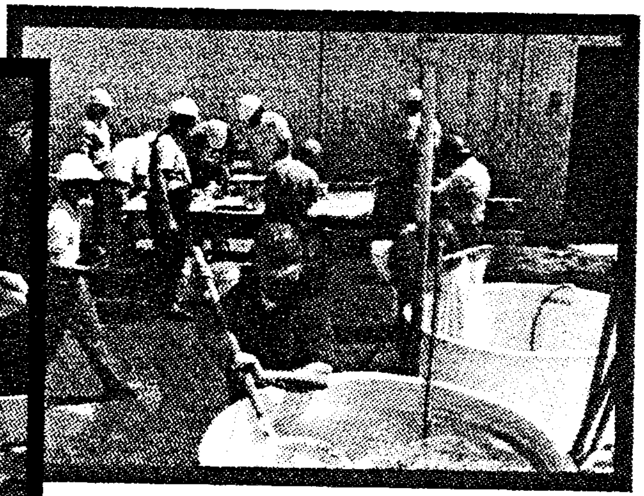


Figure 2. Schematic of the Bureau of Reclamation's Tracy Fish Collection Facility, Tracy, California. (* indicates release site; arrows indicate direction of flow)



Tracy Fish Collection Facilities